AD-760 044

IONOSPHERIC MODELING

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Prepared for:

Office of Naval Research

1973

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5285 Port Royal Road, Springfield Va. 22151

AD 760044

Quarterly Technical Report

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Contract Number: N00014-67-A-0220-0004

ARPA Order Number: 2266/8-11-72

Program Code Number: 3F10

1 October 1972 - 30 September 1973

$54,101

Scientific Officer: Director, Physics Program
Physical Sciences Division
Office of Naval Research
Department of the Navy
800 North Quincy Street
Arlington, Virginia 22217

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 2266

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IONOSPHERIC MODELING

E and F Region (100-500 km)

A computer code has been developed that will calculate the time-varying, vertical ionization distribution between 100 and 500 kilometers altitude for the polar ionosphere. The code produces ionization from both the solar ultraviolet flux and by auroral electron precipitation down the geomagnetic field lines. The distribution of ionization into the various ion species is traced through ion-chemical reactions, which are specified by the user. At present, 66 reactions can be accommodated. The ion-chemical reactions form a set of production and loss terms, which can be folded into the species continuity equations to calculate the time variable species density. A typical continuity equation can be written

$$\frac{\partial N_i}{\partial t} = P_i - L_i - \mathrm{Div}(N_i \vec{V}_i) \qquad (1)$$

where P_i, L_i, V_i, and N_i are total production rate, loss rate, velocity and number density for the ith species. An equation such as (1) must be written for each species whose density is varying with time; a complete solution for n species requires the simultaneous solution of n continuity equations. The divergence term in equation (1) represents the rate of change in the local density due to motion of particles. This term may take on a variety of forms, depending upon the complexity of completeness one wishes to specify the species densities and their velocities. If motion is ignored, $\mathrm{Div}(N_i V_i)$ may be considered zero, and the resulting equation is a first-order ordinary differential equation. If molecular diffusion is desired, then the divergence term takes the form

$$Div(N_i V_i) \approx a(z)N_i + b(z)\frac{\partial N_i}{\partial z} + c(z)\frac{\partial^2 N_i}{\partial z^2} \qquad (2)$$

where a, b, and c are coefficients that depend upon the kinetic properties of the gas; i.e., temperature, velocity, mobility, collision rate, etc., and gravity. Substituting (2) into (1) produces a second-order partial differential equation which is much more difficult to solve than an ordinary differential equation. If three-dimensional winds and pressure gradients are included in the model, the divergence operator produces partial derivatives in three coordinate directions, and the resultant partial differential equation in 3 space variables and 1 time variable becomes extremely difficult and time consuming to solve numerically. Our initial calculations neglect all motion. Thus, these calculations will be of limited use except to evaluate production and loss terms and to provide ionization profiles which can be compared with profiles obtained with vertical diffusion. In order to include vertical diffusion, the subroutine that solves the system of continuity equations will have to be replaced. A copy of such a computer code is now in house and is presently being evaluated.

A flow chart of the computer program is shown in figure 1. The user has the option of equal altitude increments or random altitudes. Densities for O, O_2, and N_2 are generated from the atmospheric model of Jacchia [1971]. Initial densities for the other species in the system may be input or are assumed to be 10^{-6} times the N_2 density. Data on the atom composition and total concentration and on charged species are input so that checks on the charge and mass balance can be made.

Ionization is produced by both solar flux and auroral particles. These two processes are further subdivided into daytime and nighttime

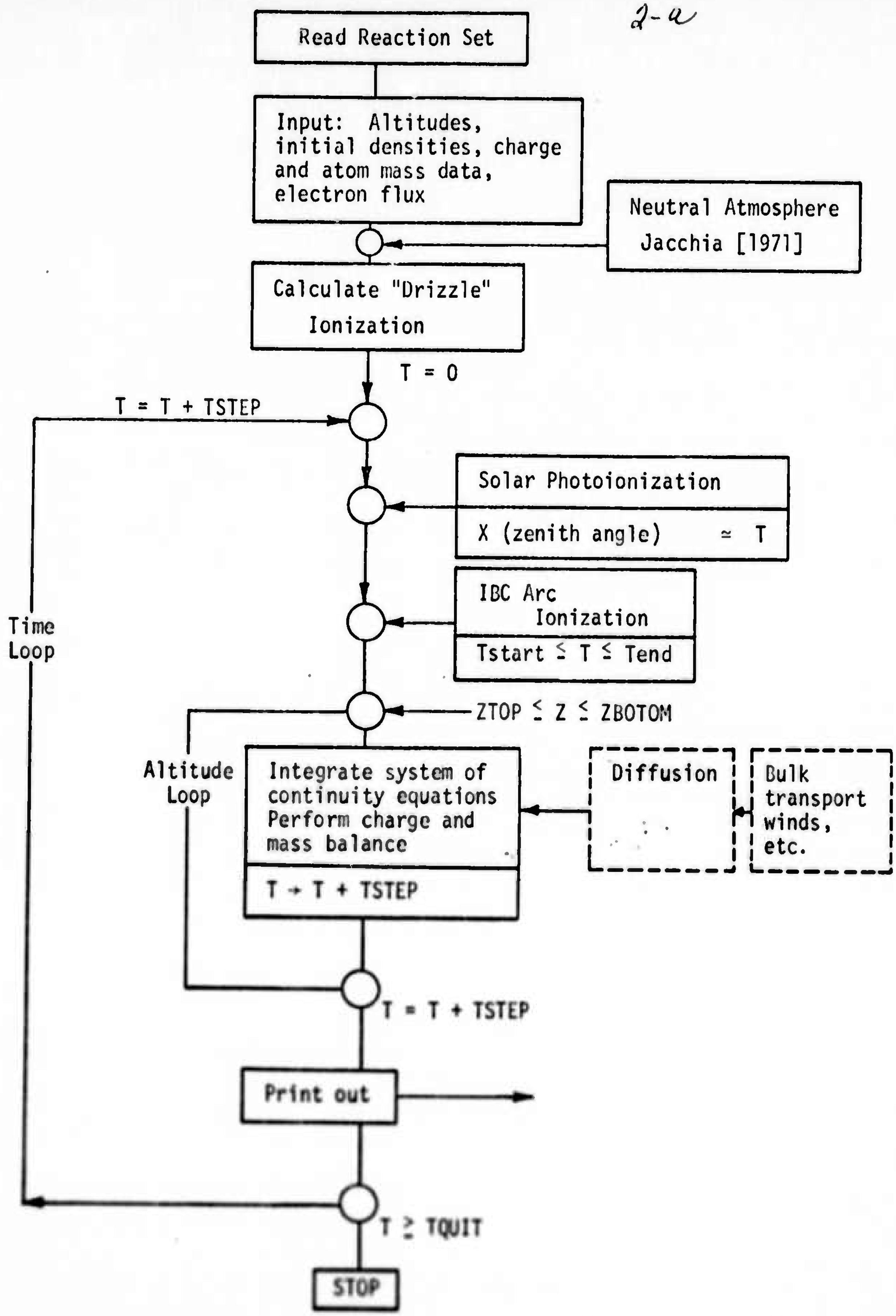

Figure 1. Flow Diagram for Computer Program to Calculate Polar Ionosphere

solar fluxes and into drizzle particles and arc particles.

The calculation of ionization rates by solar ultraviolet radiation is based on the derivation originally presented by Chapman [1931] and extended to a multispecies gas by Swider [1964]. To calculate the ionization rate at a given altitude, it is necessary to integrate the absorption of the solar flux from the top of the atmosphere down the ray path to the height of interest. The net solar flux that remains is then available to ionize whatever neutral atmospheric species that might exist at the given altitude. The difficulty with this calculation is that the solar spectrum is composed of both emission bands and lines and each wavelength interval must be handled separately. In addition, the solar absorption and ionization cross-sections of the atmospheric gases show considerable structure and it is necessary to carefully correlate cross-section data in order to match the cross-sections to the solar lines and bands. Above 100 km the photoionization and photoabsorption cross-sections of Stolarski and Johnson [1972] have been used, since these cross-sections correspond with the solar flux lines and bands measured by Hinteregger [1970]. These data cover the solar spectrum between 30-1027 Å, which is the important part of the spectrum for the E and F layers.

A nighttime photoionization source has also been incorporated into the computer code. This source is based on solar hydrogen and helium emission lines, which are resonantly scattered to the nighttime ionosphere by the hydrogen and helium gases of the earth's upper atmosphere. Ogawa and Tohmatsu [1966] first suggested the brightness of these sources (HLyβ 1026 Å--10 rayleighs, HLyα 1216 Å--4 kilorayleighs, HeI 584 Å--10 rayleighs, HeII 304 Å--1 rayleighs) and both Chen and Harris [1971] and Fujitaka et al. [1971] showed that this scattered radiation would be sufficient to account for the preservation of the nighttime E layer. The initial nighttime model is simplified by assuming a constant emission brightness throughout the night, but this will eventually be replaced with a calculation of the multiple-photon scattering in spherical geometry.

Calculation of the auroral ionization rates is based on an empirical relation developed by Lazarev [1967] from laboratory data. It has been found experimentally that when a monoenergetic beam of electrons is directed to a gas, such as N_2, O_2, air, etc., that the rate of ionization and depth of penetration into the gas by the beam depend on the density of the gas, the initial energy of the electrons in the beam, and the flux of the electrons, but are insensitive to the composition of the gas. It is also found that on the average, each electron in the beam loses about 34 eV per collision as it slows down. An expression was developed by Lazarev, based on these observations and represents an empirical fit to laboratory data, which calculates the ionization rate and depth of penetration for an electron of a given energy. To make Lazarev's equation applicable to the ionosphere, we need to specify the energy spectrum (flux as a function of energy) of the incoming electrons at the "top" of the atmosphere. Rocket and satellite observations have shown that the energy spectrum of auroral electrons is highly variable; therefore, the computer program has been written to accept any energy spectrum as input data, or to generate its own, according to the type of aurora desired (IBC class).

The calculation proceeds as follows: The electron flux as a function of energy is either read in or generated internally as an exponential function of energy. For the case of the internal particle spectrum, a parameter must be specified to designate the IBC type aurora. These electron fluxes are the fluxes at the "top" of the atmosphere (500 km). The mass density of the atmosphere is then integrated downward from 500 km and at each height the penetration depth and ionization rate are calculated from Lazarev's equation. Summing over the entire energy spectrum yields the total ionization rate, which is then proportioned between the species in proportion to their relative abundances.

The low-energy electron fluxes that produce the "drizzle" ionization are based on the electron spectrum observed by Burch [1968].

The computer code has been written so that the photoionization due to the solar flux is time dependent through the solar zenith angle. The "drizzle" ionization is presently assumed to be constant with both time and latitude. The auroral arc ionization is turned on and off at times specified by the user. This allows simulation of an arc of any duration at any time during the day or night.

Thus, ionization profiles between 100-500 km can be calculated at a given latitude throughout the day. By choosing different latitude values, a complete ionization map can be generated for the polar ionosphere.

D Region (30-100 km)

In our attack on the D region problem, we are following a philosophy in which the sophistication of the model grows in time. As a consequence, our current work is involved with the completion of many of the subroutines that we intend to use. Three production sources are planned for incorporation into the D region model. These include modifications of the solar photon absorption and the auroral electron calculations as they are now being developed for the F region problem. In addition, we are adapting production rate calculations due to solar protons and alpha particles as described by Adams and Masley [1965]. At a later time, it is planned that brehmstralung effects will also be included; for some types of events, this may be an important low-altitude ionization source. At this time we will also extend the electron ionization calculation to include relativistic effects.

Electron density calculations will involve the computation of electron loss rates. In order to be completely general, this term must depend upon time, altitude, and electron density. The plan is to begin the program with a semi-empirical set of these coefficients calculated by using experimental profiles and an extension of the two-ion model as described by Adams and Megill [1967] as a means of interpolating between the various sets of data that are available. The extension will essentially create a four-ion model since two types of positive ions will be considered in order to take into account the fast recombination rates of the "hydrated" positive ions. Subsequent versions of this calculation will include production of positive ion profiles for comparison with mass spectrometric data where desirable. It is planned to have a working program by the end of the summer with future work going toward the extensive ion chemistry calculations and sophistication of the production rate programs.

At present it is not planned to attempt a complete ion and neutral chemistry calculation in a single program. The minor species chemistry in the neutral chemistry models is poorly known and, as a consequence, the mixture of these models would perhaps confuse the issue more than clarify it. We plan, instead, to make extensive files of the diurnal and perhaps seasonal variations of the neutral species and use these as a basis for our ion chemistry calculations.

Figure 2 shows the computer program outline.

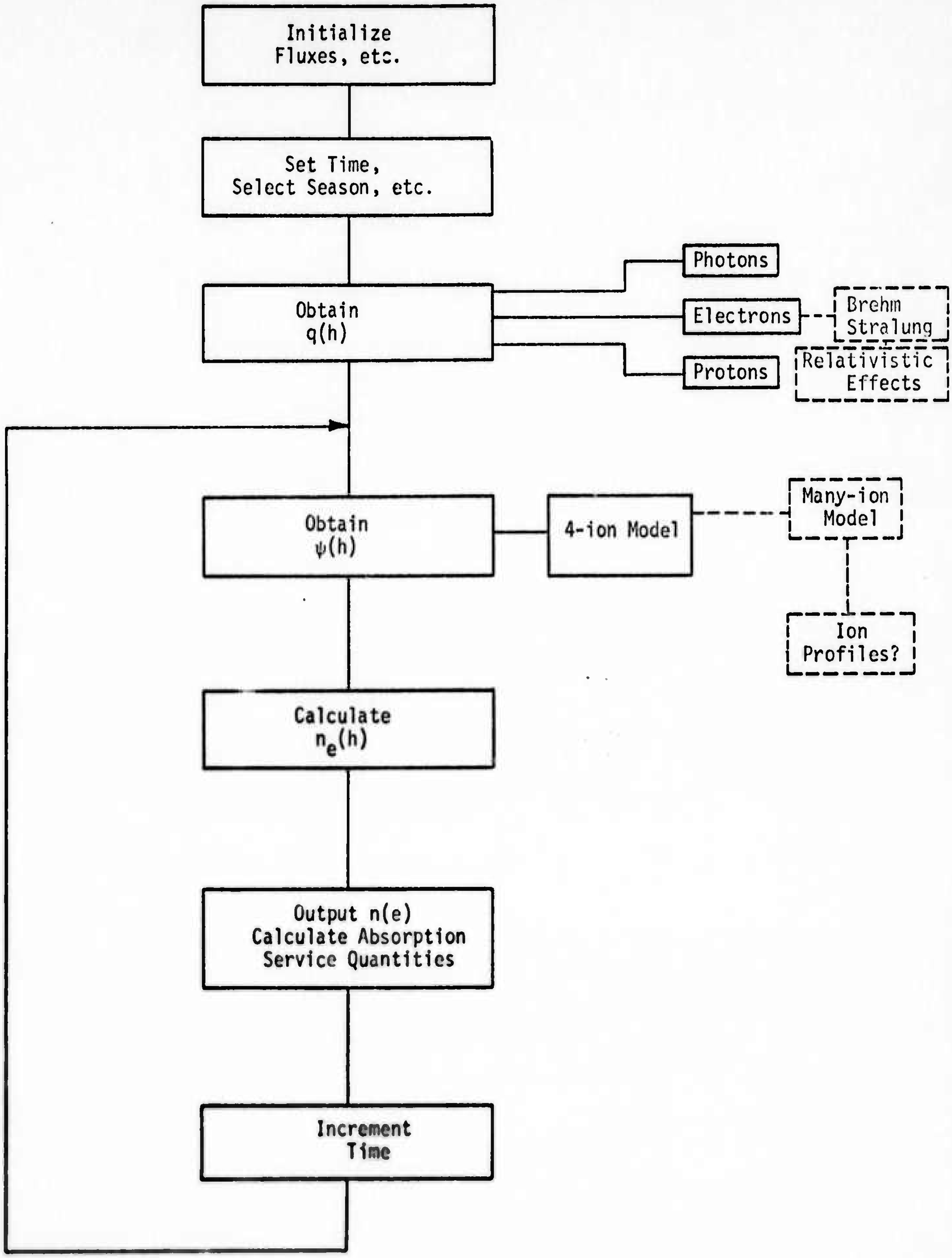

Figure 2. Computer Program Outline for the D Region

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